CONSTRUCTION & TEST OF FOUR CYCLE GASOLINE ENGINE

BY

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CONSTRUCTION AND COMPARATIVE TEST OF A FOUR CYCLE GASOLINE ENGINE ARRANGED TO OPERATE WITH AND WITHOUT AN AUGMENTED CHARGE OF AIR

A THESIS

PRESENTED BY

DAN MONROE STUMP

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN MECANICAL ENGINEERING

HAVING FINISHED THE PRESCRIBED COURSE OF STUDY IN
MECHANICAL ENGINEERING

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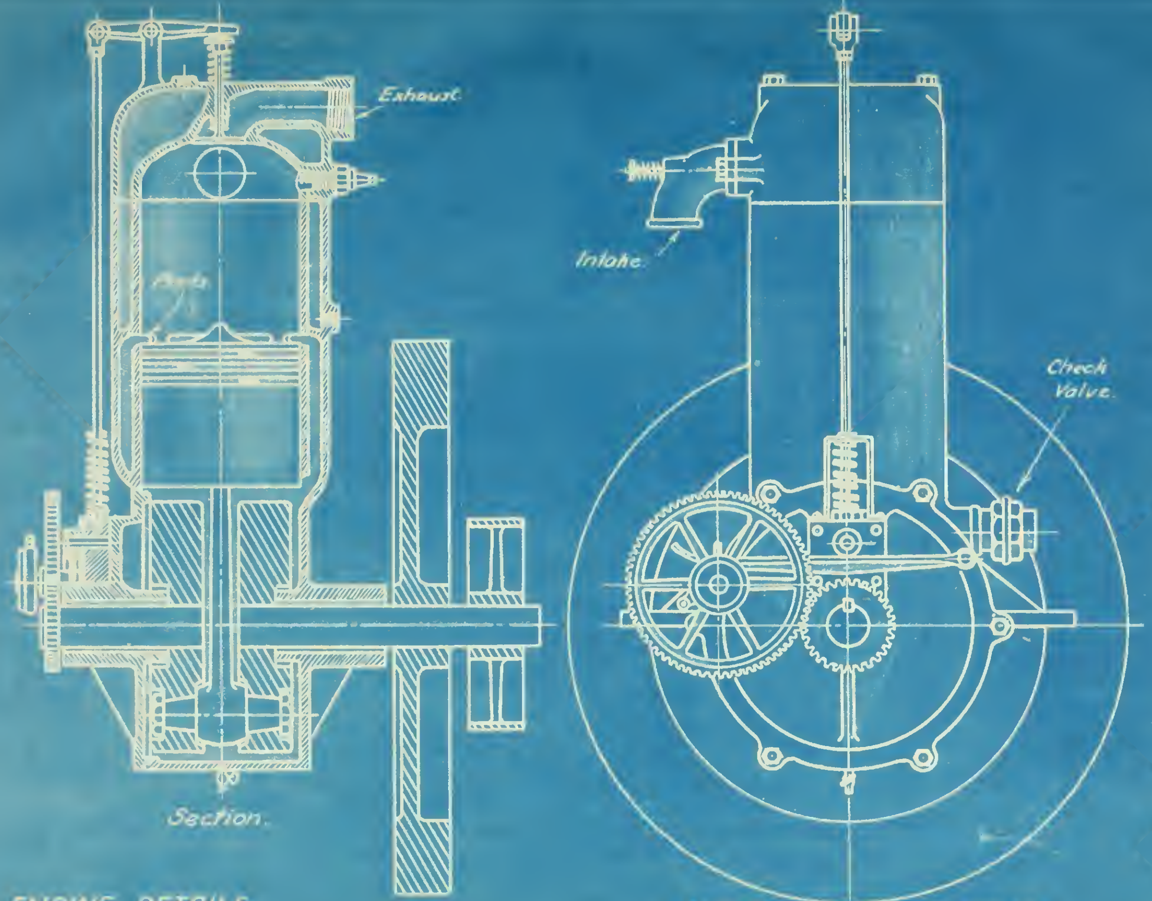


Section.

Gear side of engine.

ENGINE DETAILS.

[illegible] May 29 1913.

CONSTRUCTION AND TEST OF A FOUR CYCLE GASOLINE ENGINE ARRANGED TO OPERATE WITH AND WITHOUT AN AUGMENTED CHARGE OF AIR.

OBJECT:

To investigate the operation and economy of a four cycle gasoline engine, and to determine the practicability of forcing charges of air into the cylinder at the end of each stroke by means of a crank case compressor and a properly arranged port, such operation being calculated to increase the explosive pressures and produce a scavenging action in the cylinder.

GENERAL CONCLUSIONS:

From the results obtained the following general conclusions were drawn:

The proposed admission of an auxiliary charge of air at the bottom of each stroke proved to be entirely impracticable.

An auxiliary exhaust port uncovered by the piston at the bottom of its stroke produces a much better scavenging action of the cylinder during the exhaust, so increasing the horsepower developed by allowing a greater effective speed and higher

and higher explosive pressures to be developed in the cylinder.

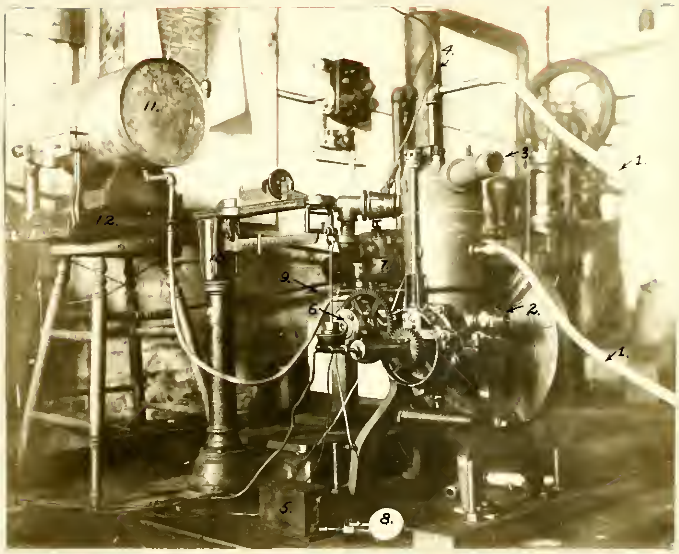
The engine running with the auxiliary port was not nearly so economical in fuel consumption as when running without, and a very uncertain mixture was admitted when the charge was throttled to allow the engine to accomodate varying loads.

ENGINE:

The engine upon which the test was made, designed and constructed by the author, was originally designed to operate upon a two stroke cycle, the feature of the engine being a cam operated poppet exhaust valve in the head, which arrangement allowed the gases to pass in through one end of the cylinder and out the other, such action being calculated to allow a better scavenging action than the usual two cycle arrangement of ports in which the gases are deflected up by a baffle and pass down again to the exhaust port. The engine operated very well up to 500 R.P.M., but above that the exhaust opening proved insufficient to handle the gases in the almost instantaneous time allowed by the cycle.

The engine was then redesigned to operate upon a four stroke cycle. An automatic poppet valve carry-

ENGINE ARRANGED FOR BRAKE TEST.



1- Cooling water leads.
2- Crank case check valve
3- Exhaust pipe
4- Pipe to manograph
5- Spark coil.
6- Timer.
7- Carburetor.
8- Tachometer
9- Prony brake arm
10- Prony brake scales.
11- Gasoline tank.
12- Gasoline tank scales.

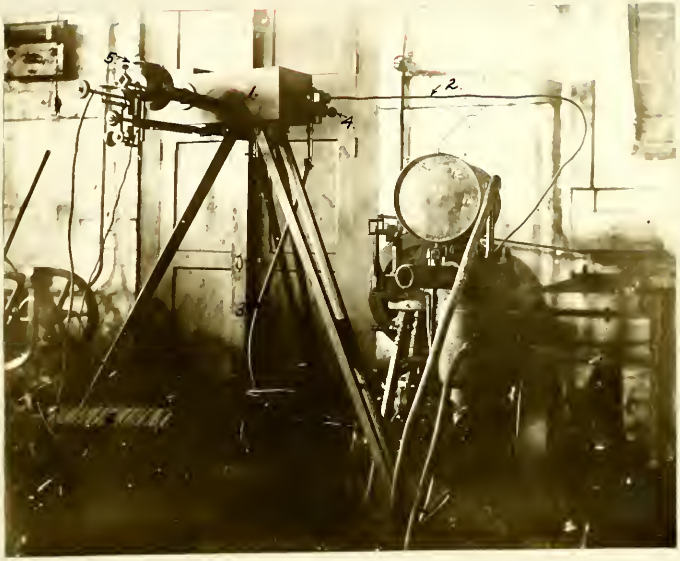
ing the carburetor was inserted in the cylinder head, also two to one pair of gears along with a properly designed cam and suitable linkwork was arranged to operate the exhaust valve. A properly arranged timing device was constructed and a set of removable blocks were fitted to close the intake passage from the crank case to the cylinder.

The general construction of the engine is shown on the accompanying plate. The cylinder had a bore of 4½ inches with a stroke of 4 inches, giving a displacement of $V_d = .7854 \times 4\frac{1}{2} \times 4$ or 63.6 cu. inches. The depth of water in the cylinder when the piston was partly lowered after the clearance space had been filled with water with the piston at the top of its stroke was 1.12 inches. This gave a clearance volume of $V_c = .7854 \times 4\frac{1}{2} \times 1.12$ or 17.8 cu. inches. Using the adiabatic formula for compression $PV^n = C$; allowing p to be 12½ lbs. and n as 1.3 the compression pressure became $p = p\left(\frac{V_d + V_c}{V_c}\right)^n = 12\frac{1}{2}\left(\frac{63.6 + 17.8}{17.8}\right)^{n=1.3} = 78$ lbs. per square inch.

The crank case compression, when the engine was turned over by hand and measured with a Bourdon guage, was nine pounds guage.

A 1.5 inch diameter mechanically operated exhaust valve opening to a 1½ inch pipe, and a 1.25 inch

ENGINE WITH MANOGRAPH.



1- Manograph

2- Pipe from cylinder to diaphragm

3- Flexible shaft

4- Horizontal adjusting screw

5- Arc lamp

6- Carbon plate rheostat.

diameter automatic intake valve opening to a 1 inch pipe were located in the cylinder head. The valve lift of the exhaust valve was 5/16 of an inch and a stop was provided which limited the lift of the automatic valve to 5/16 of an inch. The exhaust valve was operated by means of a cam, the motion being transmitted through a lever working on a roller, which was attached to a rod, the upper end of which operated a rocker arm, which in turn operated the valve.

A one inch Schelber carburetor furnished the mixture and a jump spark plug located in the cylinder head provided for ignition. The cylinder and head were water jacketed to provide for cooling and an oiler leading to the crank case supplied oil for a "splash" system of lubrication.

A one inch automatic valve was located in the closed crank case. A passage terminating in a port in the cylinder wall, the port being uncovered by the piston at 34° from the bottom center, connected the cylinder chamber with the crank case. Removable blocks were fitted,which allowed this passage to be closed when desired.

APPARATUS:

The following apparatus was used in conjunction

with the test:

A Prony brake with its accessories, for determining the torque.

A Tachometer for determining the exact speed.

An optical indicator with its accessories for determining the actual pressure condition within the cylinder during operation.

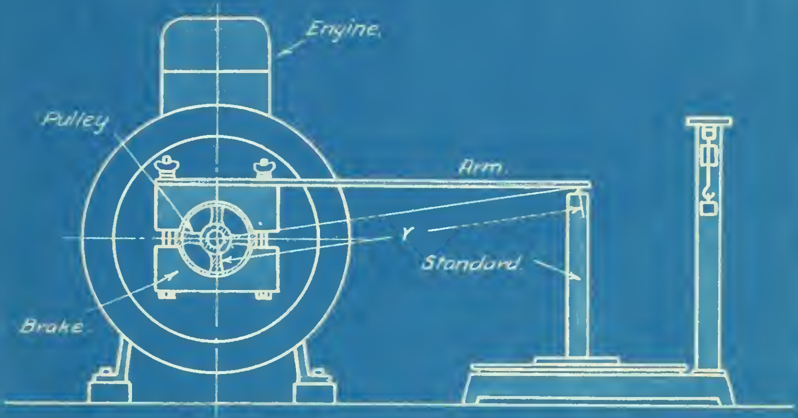
A small weighing tank for measuring the gasoline consumption.

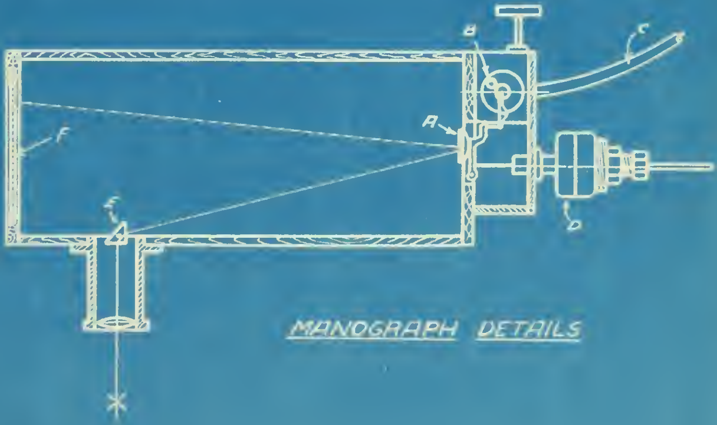
The accompanying photographs show the arrangement of this apparatus.

The Prony brake, operating on a 6 inch cast iron pulley with a $2\frac{1}{2}$ inch face, keyed to the engine shaft, was made of two blocks of wood turned to the required size, these blocks being connected by bolts by means of which the pressure of the brake was controlled. An arm fastened to one of the blocks transmitted the pressure to a small pair of platform scales through a standard upon which was mounted a knife edge. The accompanying sketch shows the construction of the brake and the arrangement of its accessories.

The Tachometer used was made by Schuchardt and Schutte, and utilized centrifugal force in moving a needle proportional to the speed of its pointed shaft, which was held against the rotating engine shaft, so

PRONY BRAKE DETAILS.





MANOGRAPH DETAILS

that the R.P.M. could be read directly on a graduated dial.

An optical indicator was used because an ordinary indicator was not adapted for the high rotative speeds, the inertia of its moving parts distorting the diagram.

In this instrument a mirror, which is deflected in one direction by changes of pressure in the cylinder and in a direction at right angles to the first motion by the motion of the piston is illuminated so as to trace a beam of light upon a ground glass screen or upon a sensitive photographic plate. Referring to the accompanying sketch, the small mirror "A" is deflected in one direction by the small crank operated in unison with the engine piston by the revolving shaft "B" and connected to the engine shaft by the flexible shaft C. The mirror is deflected at right angles by the cylinder pressure acting against the diaphragm "D". The mirror is illuminated by a small hand fed 90° arc lamp, the beam of which is reflected by the adjustable prism "E".The diagram is traced upon the ground glass screen "F".

The instrument was mounted on a wooden tripod, the diaphragm being connected to the cylinder by a

3/16" copper tube attached to a 1/8 inch cock screwed directly into the cylinder head. The current for the lamp was taken directly from the 110 volt light lead, a carbon plate rheoatat being used to regulate the voltage. The flexible shaft was connected by a small taper fitting screwed into the end of the engine shaft.

The gasoline was held in a galvanized iron tank placed upon a small pair of platform scales. The tank was connected to the carburetor by a rubber tube, the spring in the copper tube used at first, having been found to affect the scale readings.

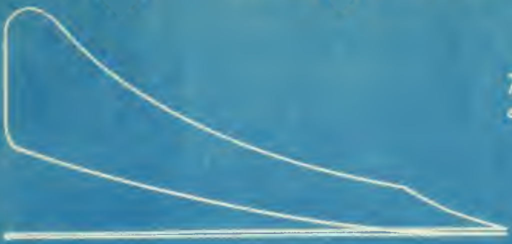
Cooling water was furnished directly from the city main, connection between the main and jacket being made by means of rubber hose. The flow of water was regulated by valves in the main. Ignition current was furnished by a set of storage batteries.

ENGINE ADJUSTMENT AND OPERATION:

Before the tests were run the engine was adjusted, with the help of the manograph, to run under its best operating conditions.

At first, with the blocks adjusted to close the passage between the cylinder and the crank case, the engine would not operate steadily enough for a manograph card to be observed. When the engine was

MANOGRAPH CARDS



Typical card showing the events well balanced.

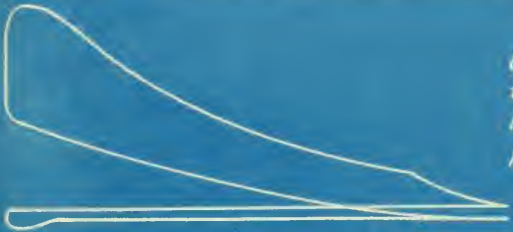


Fig. 1.
Card showing effect of throttling the charge or having a choked inlet passage.

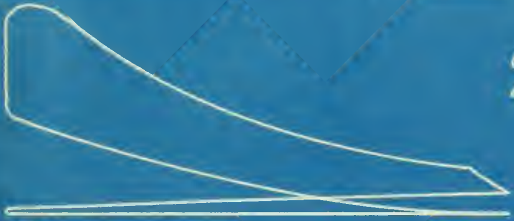


Fig. 2.
Card showing the effect of a late exhaust opening.

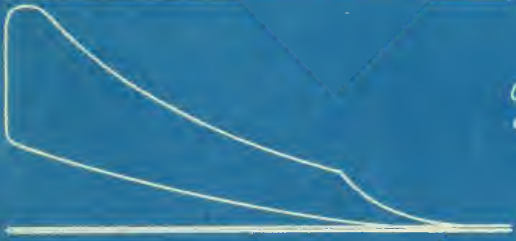


Fig. 3.
Card showing the effect of an early exhaust opening.

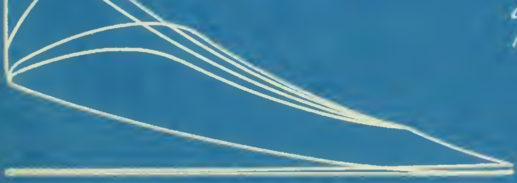


Fig. 4.
Card showing the effect of a variable or slow burning mixture.

primed, a strong explosion took place, but the engine would stop after a few revolutions, giving every evidence of a too lean mixture. Several carburetors were tried all possible carburetor adjustments made, but the trouble was not remedied. The cause of the trouble was located in the exhaust valve spring, which, due to the engine having a larger exhaust valve area than an intake valve area, a much stronger spring was required on the exhaust than on the intake to prevent air being drawn back through the exhaust valve during the suction stroke, so producing a non-explosive charge. The spring was replaced by a stiffer one, and that trouble vanished.

The engine then ran regularly at low speed, that is,under 400 R.P.M., but at any higher speed the torque rapidly decreased. It was noticed that throttling the charge had very little effect upon the running of the engine. When a manograph card was observed a broad space appeared between the exhaust line and the suction line with a decided dip at the beginning of the suction line. This is shown in Fig. 1 in the accompanying sheet of indicator cards. The stop regulating the opening of the intake valve was set to permit the valve to open 1/8 of an inch. When it was

adjusted to allow the valve to open 5/16 of an inch the card became normal, and the engine torque became greater than it was before, and remained so at a higher speed, before it began to fall off. The engine torque and speed could then be nicely controlled with the throttle.

The most efficient opening of the exhaust valve was determined by the observation of the manograph cards. When set later than 35 before the bottom dead center, a card similar to that shown in Fig. 2 in the accompanying sheet of indicator cards was obtained. The exhaust line sloped considerably indicating that the engine was exhausting under considerable back pressure during the first part of the exhaust stroke. When the valve was set to open earlier than 35° before the bottom center, the expansion line dropped early, so lowering the mean effective pressure of the cycle. Such a card is shown in Fig. 3. The valve was set to open 35° before the bottom center, and to close at the upper dead center.

The spark was adjusted until the manograph card showed the explosive pressure rise, occuring just at the end of the compression stroke, at a speed of about 500 R.P.M. the advance was about 12°, and it was greater or less in proportion to the other speeds at which the engine was run.

When the blocks which closed the passage between the crank case and cylinder were removed along with the check valve in the crank case, the operation of the engine changed materially. Starting became much harder and the needle valve of the carburetor had to be opened further in order to have the engine operate regularly. Above 600 R.P.M. the engine ran smoothly, and the torque was greater than it was with the port closed, but below that speed the engine ran irregularly. When the incoming mixture was throttled, the effect was more pronounced, the engine often "missing" altogether. The explosion lines of a manograph card did not overlap at this low speed, but each explosion seemed to have a different pressure. This was caused by the variable mixture produced by the air and burned gases leaking back through the port at the bottom of the suction stroke. A typical card is shown by Fig. 4 on the accompanying sheet of indicator cards. With the port opened the exhaust valve setting was not changed but better results were obtained by slightly advancing the spark.

HORSE POWER AND FUEL CONSUMPTION TESTS.

Two short tests were made to obtain data from which the horse power and fuel consumption of the

engine, operating first with and then without the auxiliary exhaust port, might be compared.

Both runs were made with an open throttle since satisfactory operation could not be obtained, when the engine, while operating with the auxiliary port, was throttled. The issuing jacket water was kept near the boiling point, the carburetor adjusted and the spark advanced to give the best operation during each run.

The author was assisted in these tests by MR. Alex F. Robertson and Mr. Edward L. Nelson, both students at the Institute. Readings of R.P.M. and brake load were taken each run, and initial and final gasoline scale readings were taken. The brake tare was 5.20 pounds, and the brake arm length was 24 inches. The following results were obtained.

WITH AUXILIARY PORT CLOSED.

SPEED	BRAKE SCALE READING	NET LOAD	B.H.P.	GASOLINE SCALE READINGS	GAS USED	GAS PER BHP. HR.
350	13.10	7.90	1.05	14.72		
500	12.65	7.45	1.41			
600	12.00	6.80	1.55			
700	11.45	6.25	1.66			
800	10.30	5.10	1.55			
900	9.10	3.90	1.35	14.14	.58	.82

WITH AUXILIARY PORT OPENED.

SPEED	BRAKE SCALE READING	NET LOAD	B.H.P.	GASOLINE SCALE READINGS	GAS USED	GAS PER B.H.P. HOUR.
3.50	13.40	8.20	1.08	10.12		
500	14.30	9.10	1.73			
600	14.30	9.10	2.08			
700	14.30	9.10	2.42			
800	14.30	9.10	2.77			
900	13.70	8.50	3.11			
1000	11.40	6.20	2.34	8.55	1.57	1.23

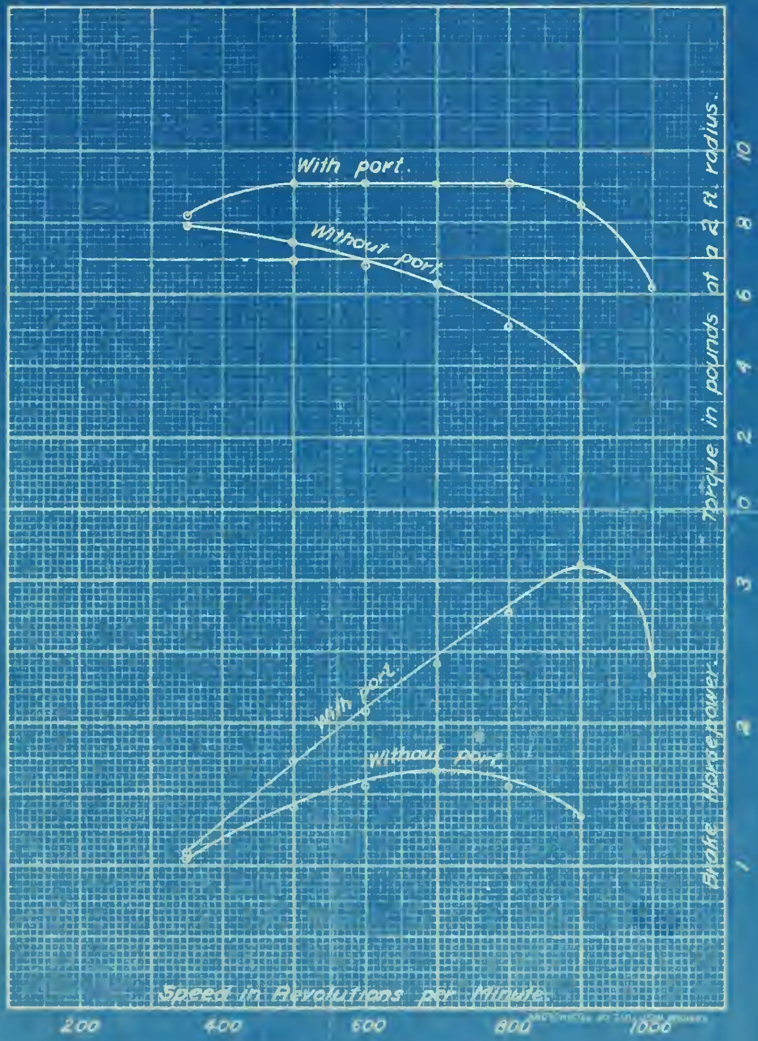
The following set of sample calculations for the first readings show the method employed in calculating the results.

The net load was obtained by subtracting the brake tare from the Brake scale reading.

$$13.10 - 5.20 = 7.90 \text{ pounds.}$$

The brake horse power was obtained by substituting in the formula $B\,H\,P = \frac{2\pi r N P}{33000}$ in which r is the brake arm length, N the number of revolutions per minute and P the net brake load. The distance 2 r N through which the force Pacts divided by the horse power constant 33000 gives the actual developed horse power.

$$B\,H\,P = \frac{2 \cdot \pi \cdot 2 \cdot 790 \cdot 350}{33000} = 1.05 \text{ horse power.}$$



HORSEPOWER AND TORQUE CURVES.
Engine operating with and without auxiliary exhaust port.

The average gasoline consumption was obtained by taking 1.44 the average horse power developed during the thirty minutes, and dividing it by 60/30 of 58, the total gasoline used, giving 82 pounds of gasoline per brake horse power hour.

From this data curves were plotted, showing the torque and developed horse power at the different speeds.

OPERATION WITH THE AUGMENTED AIR CHARGE.

When the check valve was inserted in the crank case, theoretically causing a charge of air to be forced from the crank case into the cylinder through the port each time the piston was at the bottom of its stroke, real difficulties began. After many futile attempts the engine was started by holding the check valve open, so allowing the engine to operate upon the regular "ported" cycle.

When the valve was allowed to operate, the engine could be kept running only by opening the needle valve of the carburetor a half a turn beyond the former adjustment and its operation then was very uncertain. The manograph cards obtained were so irregular that no conclusion could be drawn from them. More even running was obtained at a high speed with no load on the engine by setting the exhaust valve so that it

opened 90° between centers, but then the engine would not pull even a light load. The manograph cards indicated a very uncertain mixture.

The conclusion drawn from these results was that a portion of the exhaust gases, at the end of each stroke, instead of being blown out by the charge of air from the crank case, as it was calculated they would be, were forced into the crank case, from which at the end of the suction stroke they were returned to the cylinder, weakening the mixture so that successful operation of the engine was impossible. The charge of air, which was calculated to increase the explosive pressures probably never entered the crank case, the pressure there remaining above atmospheric. At least the incoming air, if any did enter, was so charged with burnt gas that a decrease instead of an increase in explosive pressure was obtained.

This all leads to the general conclusion that the admission of the proposed auxiliary charge of air at the bottom of each stroke was not merely non-advantageous, but entirely impracticable in an engine with an open passage between the crank case and the cylinder.

Respectfully submitted to the
President and Faculty,

May 29, 1913.

Dan M. Stump.